INNOVATIVE APPROACHES TO NOISE REDUCTION IN METALLURGY.

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ABSTRACT
Ferrous metallurgy takes a leading role in Russia and it is a rapidly growing branch in Egypt. The occupational morbidity, including noise-induced diseases, of ferrous metallurgy workers is about one third of the total occupational morbidity. The noise levels at the workplaces of metallurgical workers exceed the limit values by 4-26 dB(A). The limit levels in the residential territory situated in the vicinity of metallurgical enterprises are also exceeded. In Russia to reduce the impact of negative factors on the population and workers of metallurgical enterprises, the best available technologies are applied. They help to reduce internal and external noise by 3-25 dB(A). In Russia, the main approach to reduce noise in the vicinity of the metallurgical enterprise is to establish a sanitary protective zone, i.e. an area where it is prohibited to locate noise sensitive objects. The size of such a zone is evaluated using noise mapping and can be decreased using noise protection measures in source and on the path of sound propagation. Such, to reduce internal noise caused by flame heating furnace it is recommended to shift to oxygen combustion technology and use modern burners. In addition, measures on sound absorption with modern types of lining were elaborated. For reduction of noise of rolling shops, a special vibration damping measures and pipe silencers were proposed. Reduction of noise on the way of its propagation is provided with technological acoustic barriers.

Keywords
Industrial noise; Metallurgy; Noise reduction; Best available technologies.

1. INTRODUCTION
Ferrous metallurgy is one of the basic branches of heavy industry in Russia, the products of which are used in mechanical engineering, construction, and transport. The share of ferrous metallurgy in the volume of industrial production in Russia is about 10%. Ferrous metallurgy includes more than 1.5 thousand enterprises and organizations, 70% of them are city forming, and the number of employees is more than 660 thousand people. Russia ranks fourth in the world in steel production and export [1].

The iron and steel industry in Egypt emerged in the 1950s and immediately became the main driver of industrialization. There are 22 steel industry enterprises operating in the country with a total capacity of more than 8 million tons of final products per year. In addition, domestic steel consumption is constantly growing [2].

The occupational morbidity of ferrous metallurgy workers in recent years is about 20-32% of the occupational morbidity of all enterprises. Noise is one of the most important factors affecting the health of workers, which causes such an occupational disease as hearing loss, and it also negatively affects the cardiovascular and digestive systems.

When analyzing equivalent sound levels at the workplaces of Russian steel production factories, it was found that they are estimated as 84-106 dB(A). So, the limit value of 80 dB(A) established at the workplace in Russia is exceeded by 4-26 dB(A) [3].

Researches carried out in Egypt show that the effect of noise on cardiovascular functioning is moderate, since noise affects the blood pressure [4]. Results of the noise measurement show that overall noise levels and exposure to noise in metal factories are 90-94 dB(A). The daily noise exposure of workers in factories exceeds the maximum exposure limit of 85 dB(A) established by [5]. Exposure to noise of such high intensity for long duration (10-15 years) cause biochemical changes, which make the workers, prove to cardiovascular pathology [4].

An Egyptian Law Concerning Environment [5] states the limit levels in residential building and areas sensitive to noise. The limit values in Egypt are close but a little bit higher than the ones established in Russia [6] and based on the provisions of the WHO. Though in both counties, due to high noise levels of equipment used in the process of steel production, the limit levels in the residential territory situated in the vicinity of metallurgical enterprises (55 dB(A) at the daytime and 45 dB(A) at night) are exceeded that cause negative health effect on the residents.

At ferrous metallurgy enterprises, noise sources are the following: moving process gases when they are fed into pipes and blown into furnaces, the movement of cranes, conveyors and trains, industrial and ventilation equipment, etc. Equipment that generates the highest noise levels are crushers (115-118 dB(A), screens (112 dB(A), feeders (108-116 dB(A), steel-smelting arc furnaces (116-129 dB(A), sandblasting plants (117 dB(A), grinders (109 dB(A), compressor and ventilation plants (106-118 dB(A) and equipment for rolling shops (121-125 dB(A) [7].

Thus, industrial noise in the production of ferrous metals is quite high and it is one of the most unfavorable factors in the risk of occupational pathology. General medical and individual preventive measures are insufficient in the fight against industrial noise. A very important measure to reduce noise at the source of its emission is the technical improvement of the equipment; on the path of noise propagation, measures for sound insulation, sound absorption, vibration damping and noise shielding are applied to ensure maximum permissible levels in residential buildings. The modern methods to reduce noise in metallurgy are analyzed in this paper.

2. BEST AVAILABLE TECHNOLOGIES FOR NOISE REDUCTION

To reduce the impact of negative factors on the population and workers in Russia, the best available technologies (BAT) are applied. The BAT concept was developed in 2014 and implemented in accordance with the Federal Law on Environmental Protection [8]. The combinations of criteria for achieving environmental objectives to determine the best available technology are:

- the lowest level of negative impact on the environment per unit of time or volume of work or service;
- economic efficiency of its implementation and operation;

- application of resource- and energy-saving methods;
- implementation of this technology at two or more facilities that have a negative impact on the environment.

In accordance with the Federal Law, engineering and technical guidelines have been developed for various industries, containing the best available technologies (BAT) to reduce the negative impact on the environment, including noise. The main BATs recommended for noise reduction in industrial plants are as follows [9]:

- BAT 6-1. Development and implementation of a plan for noise control and prevention as a part of the environmental management system.
- BAT 6-2. Appropriate placement of equipment and buildings.
- BAT 6-3. Proper implementation of operational measures.
- BAT 6-4. Use of low noise equipment.
- BAT 6-5. Reduction and prevention of noise generation during the use of equipment.
- BAT 6-6. Use of measures to prevent the spread of noise (noise absorption).

Development and implementation of a noise management and control plan as a part of an environmental management system is a driving force for evaluation of noise exposure and implementation of protection measures. Noise management plan includes the following documentation [9]:

- regulations containing relevant measures and deadlines for their implementation;
- regulations for noise control;
- regulations for responding to identified cases of noise generation;
- noise prevention program designed to identify and eliminate the source of noise generation, evaluate the duration of noise impacts, characterize the participation of various sources of noise generation and take measures to stop and (or) reduce noise generation;
- analysis of previous situations related to noise generation.

For metallurgical enterprises a special information and technical guide to the best available technologies [9] was developed. It acknowledges that noise is one of the main negative factors affecting workers and residents living at the vicinity of metallurgical enterprises. Technologies aimed at reducing the impact of noise by implementing one or a combination of two or more methods are shown in table 1. The acoustical efficiency of the BATs is estimated according to [10].

Table (1): Best available technologies to reduce noise in metallurgy.

Protection measure	Efficiency, dB(A)
Choosing location for noisy operations (sanitary zone)	6 dB(A) per doubling of distance (e.g. 1000 m – minus 60 dB(A)
Enclosure of noisy operations/aggregates	up to 20 dB(A)
Vibration isolation of production facilities/aggregates	5-10 dB(A) (up to 25 dB at high frequencies)
Use of internal and external insulation based on sound absorbing materials	5 dB(A)
Sound insulation of buildings (e.g. closing doors and windows in workshops and premises)	up to 30 dB(A)
Installation of acoustic barriers and/or natural barriers	up to 20-25 dB(A)
Application of silencers on discharge pipes and ventilation inlets/outlets	10-15 dB(A)
Soundproofing of ducts and fans	up to 15 dB(A)
Use of soundproofing of machine chambers	up to 20 dB(A)
Installation of sound absorbers at air outlets	10-15 dB(A)
Reducing the speed of streams in channels	18 dB(A) at twofold reduction of speed
Separation of noise sources and potentially resonant components such as compressors and channels	up to 10 dB(A)
Use of rubber shields when crushing coal and transporting pipes	3-8 dB(A)
Erection of buildings at the way of sound	Up to 25 dB(A)
Planting trees and bushes between the sensitive zone and noisy production	dB(A)

3. Sanitary protective zones

In Russia in accordance with [11], a special territory with a special regime of usage called a sanitary protective zone is established in order to ensure the safety of the population around industries that are sources of impact on the environment and human health. The size of sanitary protective zone ensures the reduction of noise exposure to values established by hygiene standards. The approximate size of the sanitary protective zone for metallurgical enterprises is 1000 m. The approximate size of the sanitary protective zone is substantiated by the design project including calculations of noise levels and is confirmed by the results of in-situ measurements.

The criterion for determining the size of the sanitary protective zone is not exceeding the maximum permissible levels of noise impact on its outer border and beyond. In the sanitary protection zone, it is not allowed to place residential buildings, recreation areas, territories of resorts, sanatoriums and rest houses, educational and children's institutions, as well as other territories with normalized environmental quality indicators in accordance with [6]. Acoustic calculations and development of sanitary protective zones are usually carried out using noise maps.

When assessing the impact of noise on the environment, specialists use modern software based on existing calculation methods. All these methods are implemented in the SoundPLAN software package, which is the world leader in calculating the noise of various objects and it is adapted for use in different countries of the world, including Russia and Egypt.

The process of developing a noise map is divided into the following stages:

- collection of initial data on the parameters of noise sources;
- development of a digital terrain model (building, relief, green spaces, etc.);
- assessment of noise characteristics of noise sources;
- development of a noise map;
- analysis of calculation results and development of action plans to reduce noise levels.

A digital terrain model is compiled based on the official publication of the terrain map, topographic survey at a scale of 1:2000 or aerial photography of the territory. On a digital terrain model, territories should be defined in accordance with their functional purpose according to [6]. The collected initial data is used to calculate the propagation of noise according to the methods approved at the state level. To calculate the noise propagation, the territory is divided into a grid with a certain step that is most appropriate for the purposes of mapping. After determining the noise levels at the calculated points of the grid, points with equal sound levels are connected by isolines, resulting in lines of equal sound levels with a certain step. The most convenient step is 5 dB(A), which corresponds to the terms of noise regulation. On the noise map, isolines corresponding to the maximum permissible levels for residential development (55 dB(A) in the daytime and 45 dB(A) at night) are emphasized. They represent the estimated sanitary protective zone of the enterprise.

Figure 1 shows an example of calculating the noise map of an industrial enterprise, which determines the estimated size of its sanitary protective zone.

a) **b)**

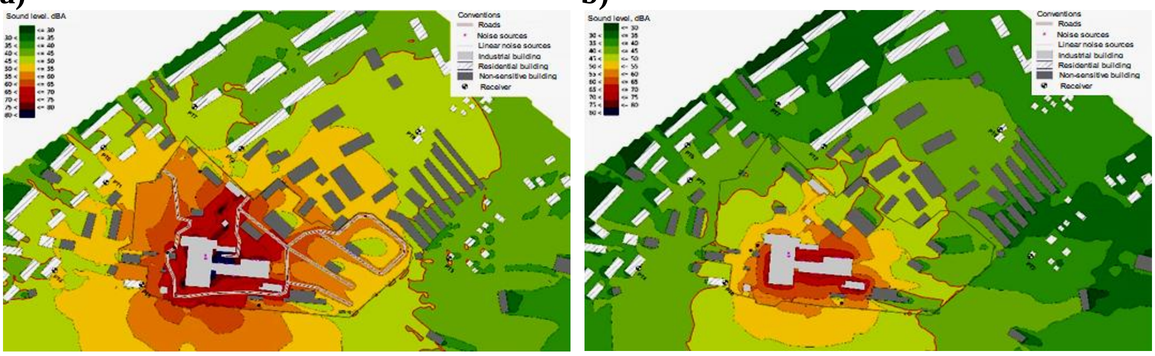

Fig. 1: Noise maps with sanitary protective zones; a) before protection measures, b) after application of protection measures.

With the help of noise maps, noise protection measures are developed that can significantly reduce the size of the sanitary protective zone. Such, the size of the sanitary protective zone of PJSC Severstal (Cherepovets) was reduced from 1000 m to the boundary of residential development, located at a distance of about 200 m from the border of the enterprise.

4. NOISE REDUCTION OF HEATING FURNACES

Flame heating furnaces, widely used in rolling shops of metallurgical enterprises, are one of the main sources of excess noise. By origin, all noise sources of flame furnaces can be divided into three groups: mechanical (noise of technological mechanisms that drive dampers, roll-out hearth, walking beams, push carts, etc.), aerodynamic (noise of gas-air mixture outflow from burners) and thermal (noise generated during fuel combustion) [12].

The noise of the mechanisms depends on the accuracy of manufacturing, fit tolerances, and the accuracy of the installation of parts. The work of auxiliary technological equipment of the furnace has a periodic nature, the total duration of work is no more than 5% of the heating cycle time, therefore, mechanical noise makes the least significant contribution to the overall noise impact. The jet of gas-air mixture flowing from the burner nozzle creates aerodynamic noise, the causes of which are turbulent pulsations in the mixing region, density fluctuations in the jet, and the interaction between these fluctuations and turbulent pulsations. The noise level of the burner depends on such parameters as the flow rate of the combustible mixture supplied to combustion, the regime of the expiration of this mixture, the length of the jet, the type of fuel burned, the presence of restrictive walls for the movement of the jet, and the interaction of each specific jet with other jets located in the expiration zone. In flame heating furnaces, these parameters depend on such technological characteristics as charge mass, temperature and metal heating mode, furnace design, type and number of burners, type of fuel and oxidizer used.

The design features of the furnace affect the reduction of noise along the path of its propagation. These factors include the design of the furnace working space and the type of lining used. Ways to reduce noise from flame furnaces can be divided into primary measures, i.e. reducing noise at the source, and secondary measures, i.e. reducing noise along its propagation path. Measures to reduce noise at the source involve reducing noise emission, and measures along the way of its propagation are aimed at sound insulation and sound absorption. Primary measures include optimization of the heating mode of the furnace, optimization of the metal heating mode, change of the burners' location. Secondary ones include optimization of the shape and geometrical parameters of the working space of the furnace, the choice of lining and sealing of the furnace.

The heating mode of a flame furnace is characterized by the type of fuel and oxidizer used, the type of burner used, the number of burners in the furnace and the way they are placed. The greatest reduction in the volume of generated smoke, and, consequently, the reduction of noise during fuel combustion, can be achieved by switching to oxygen combustion technology, i.e. to use pure oxygen as an oxidizing agent, which reduces the volume of flue gases, and, consequently, the time of their expiration, by almost 4 times, while noise levels will decrease by 5-6 dB(A).

Another way to reduce noise by improving the heating system is to choose less noisy burners. Most often, for heating domestic furnaces, burners of the "pipe in pipe" type are used. Mixing of the fuel with the oxidizer in such burners is ensured mainly due to the high flow rates of the fuel with the oxidizer, which significantly turbulizes the combustible mixture, ensuring its mixing, but at the same time increasing noise generation. When such burners are equipped with special mixing devices, the combustion of fuel goes into a kinetic mode; the size of the flame is reduced, reducing the level of generated noise. Such burners are called flameless and silent. Methodical furnaces of a new generation are currently equipped with flameless burners, which provide high environmental heating performance in terms of energy consumption, toxic gas emissions and noise generation. The acoustical efficiency of the measure to replace the burners can reach up to 10-14 dB(A).

Secondary constructive ways to suppress the noise emitted by furnaces include the choice of the optimal shape and size of the working space of the furnace, the use of sound-absorbing lining material and sealing the working space of the furnace. A flame heating furnace can be thought of as a source of heat generation enclosed in a soundproof hood. The higher the sound absorption coefficient of the walls of the hood, the lower the noise level at the work site near the furnace and in the environment. In addition, the presence of holes has a great influence on the noise level outside the furnace, since these holes not only cause heat loss in the furnace, but also cause increased noise levels emitted by the furnace. Therefore, the furnace lining must be made not only of sound-absorbing material, but also ensure the tightness of the working space during the operation of the burners. From this point of view, all batch furnaces, the working space of which is separated from the environment by special doors, have greater sound insulation than batch furnaces with open loading and unloading ends. An alternative to such furnaces are methodical furnaces with roll-out trolleys, in which the working space is closed with doors during the heating of the metal.

To evaluate the effectiveness of noise protection measures, mathematical modeling of the metal heating process in flame heating furnaces was carried out using the SoundPLAN software. The object of study was a chamber furnace with a bogie-hearth batch, equipped with gas burners.

Noise maps inside the furnace space, built using the SoundPLAN program, are shown in figure 2.

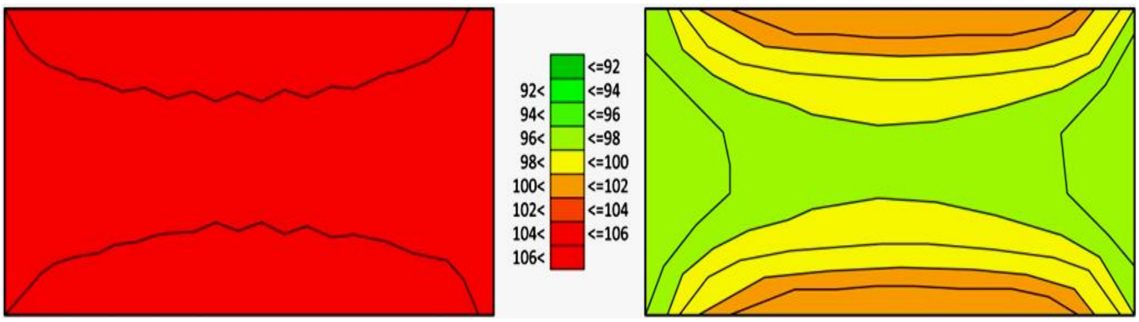

Fig. 2: Noise level in a furnace with traditional (left) and modern (right) linings.

As the calculation shows, the use of modern lining materials with a high sound absorption coefficient helps to reduce the noise levels inside the furnace by up to 14 dB(A). To assess the noise levels outside the unit, the sound insulation of the kiln walls was evaluated based on the density and thickness of the lining layers. The results of the calculations showed that the sound insulation of the furnace walls with a new lining made of ceramic fiber materials is 10 dB lower than when using a traditional lining made of refractory bricks. However, thanks to the sound absorption of ceramic fiber materials, the noise level outside the furnace can be reduced by 2 dB(A) with a new lining. Further reduction of noise levels outside the furnace can be achieved by increasing the thickness of the lining layer.

To reduce the noise of electric arc furnaces, which are a source of noise reaching levels of 130 dB(A), they are installed in gas and noise protective chambers. Figure 3 shows one of these options for placing equipment in an electric arc furnace shop [9].

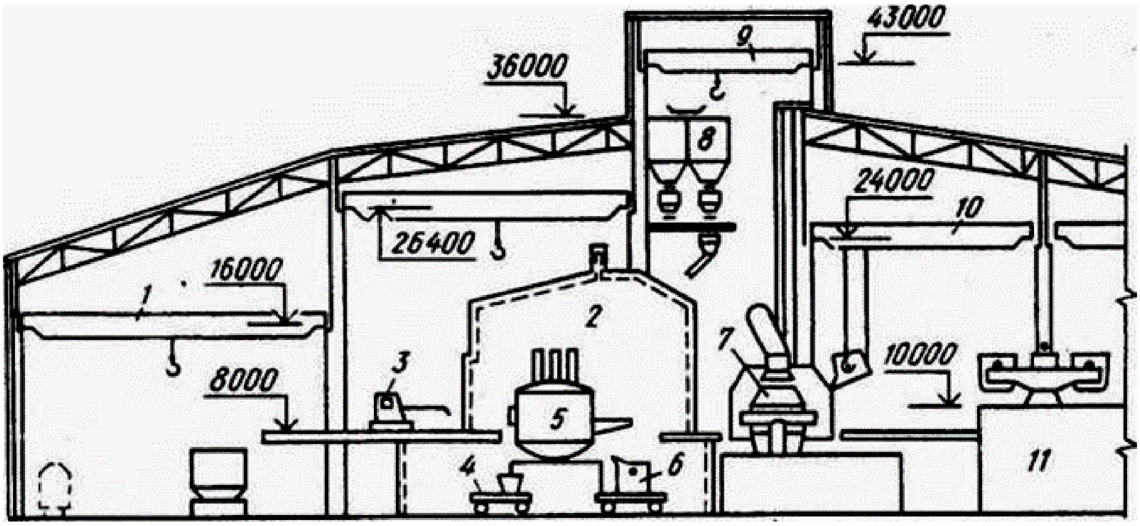

Fig. 3: Electric steel smelting facility at Russian enterprise;
1-magnetic clamshell crane, 2-noise and dustproof chamber, 3-machine for slag recharge, 4-slag carrier, 5-electric arc furnace, 6-scoop with metal scrap on a self-propelled cart, 7-argon-oxygen refining unit, 8-bunker for bulk materials, 9-hopper span crane, 10-bridge crane refining span, 11-transverse crane.

The soundproof chamber is made of materials with a high sound insulation index (for example, metal) and is lined from the inside with a non-combustible sound-absorbing material with a high sound absorption coefficient (for example, basalt fiber). To remove gases and ensure air exchange, holes are arranged inside the chamber, which, if necessary, can be additionally equipped with silencers. The effectiveness of measures for installing a noise-protective chamber on an electric arc furnace, depending on the design of the chamber, can reach 15-20 dB(A) [10].

The simplest way to reduce noise levels in the territory adjacent to the metallurgical enterprise is to increase the sound insulation of enclosing structures by closing open openings in shops with noise sources. The effectiveness of this measure is ensured by the fact that in the closed position, the sound insulation index increases from zero to 20-30 dB(A), depending on the design of the window or door.

5. NOISE REDUCTION OF ROLLING PRODUCTION

Rolling mill equipment is also a source of high noise levels. This is due to the properties of the processed material itself (metal pipes, sheets), which emits noise under various mechanical influences (impacts, movement along the conveyor, bending, etc.). To reduce the noise of rolling pipe production, it would be most expedient to cover the places of collision of metal parts with vibration-damping material and muffle the noise from the ringing of the pipes themselves [13].

The vibration damping material is a high-density elastic material that converts part of the vibrational energy into heat and increases the mechanical resistance of the walls of the lined structure. At resonant frequencies, vibration-damping materials work most efficiently, since with an increase in the amplitude of vibrations and bending deformations, the loss of vibrational energy increases.

To reduce the impact noise emitted when pipes, metal sheets and strips collide with metal elements of equipment when pipes move along a roller table or when pipes are reloaded from one section to another, it is recommended to cover such equipment elements as guides, roller tables in places where the pipes touch (with the replacement of rollers with rubber or polymeric materials), transfers, stops at the places where the pipes touch, etc.

To assess the effectiveness of measures for vibration damping, an experimental stand was made, on which the guide profile pipes were lined with vibration damping material, which is high-density rubber gaskets 2.5 mm thick, (figure 4). According to the measurement results, the efficiency of reducing the equivalent noise levels when processing the rack with vibration damping material reaches 8 dB(A).

Fig. 4: Lining with vibration-damping material for guides at pipe rolling facility.

In addition to moving along racks and roller tables, electric welding pipe production, as a rule, has a crane facility. During loading and unloading operations, pipes collide in a free state, which creates high-intensity noise. Standard noise reduction methods at the source (for example, vibration damping) are not applicable in this situation. To reduce noise levels when reloading pipes from mechanized pockets, temporary storage sites, warehouses, etc., it is proposed to use a pipe silencer, which is a sealed plug that fits snugly against the pipe [13].

The main effect of the use of silencer plugs is achieved by absorbing part of the energy with mineral wool (in the presence of an absorber at the end), reducing the angle of noise emission due to the soundproofing of holes with plugs and the effect of vibration damping (reducing the amplitude of vibrations) of the pipe walls due to the snug fit of the plug seal to the surface.

A prototype of the developed muffler consists of disks made of sheets of 12 mm thick oriented strand board, with a diameter 4 mm less than the pipe diameter. Every three disks alternate with a gasket disk made of 3 mm thick dense rubber, with a diameter equal to the inner diameter of the pipe. The edge of the discs is glued with a 4.5 mm thick foam rubber sealant. The whole structure is assembled on a stud and fixed with washers and nuts. For ease of use, the plug is equipped with a metal handle, (figure 5).

Fig. 5: Noise silencer for pipes with soundproof material.

According to the results of measurements on the experimental stand, the efficiency of reducing equivalent noise levels, depending on the configuration of silencer-plugs and the number of plugged ends, is the same for plugs with a sound absorber, regardless of whether one end of the pipe is plugged or both. At the same time, the effectiveness of measures for the use of mufflers-plugs is up to 3 dB(A).

6. REDUCTION OF EXTERNAL NOISE AT METALLURGICAL ENTERPRISES

Recently, stationary technological acoustic barriers have been increasingly used to reduce the noise of industrial enterprises in Russia. Acoustic barrier is a soundproof barrier on the path of sound propagation, which has a finite size. Behind the barrier, an area of sound shadow is formed. The main principle of operation and purpose of acoustic barriers is sound reflection. Part of the sound energy is reflected by the screen, but some passes behind it, diffracting on its edge.

Properly designed and installed without gaps and openings, the acoustic barrier provides a sufficiently high sound insulation (30-37 dB(A), determined by the material and thickness of the panels. However, due to the effect of sound diffraction around the barrier edge, its efficiency at the receiver located behind the barrier does not exceed 20 dB(A) for a thin barrier. An important element in the design of the barrier is a sound-absorbing coating located on the side of the sound source, which significantly increases the efficiency of the barrier.

An example of the successful application of an acoustic barrier is a case of Vyksa Metallurgical Plant, where a noise barrier along the electric pipe welding shop No. 3 was installed in 2019, (figure 6).

The total area of a barrier is 3,840 m^2. The barrier consists of 100 mm thick perforated metal sandwich panels with sound absorption inside. According to the data collected by the plant, the barrier has reduced the level of night noise by 10% in the nearby residential village. Measurements confirm that the permissible noise level in the area of residential development is not exceeded, i.e. the established limit of 45 dB(A) at night is observed [14].

Fig. 6: Noise barrier at Vyksa metallurgical plant along pipe electric welding shop.

CONCLUSION

Ferrous metallurgy is one of the basic branches of heavy industry in Russia and Egypt. It is characterized by the high noise levels of equipment reaching up to 125 dB(A). So, the limit values for workplaces and residential buildings situated at the vicinity of metallurgical enterprises is exceeded by 4-26 dB(A).

To reduce the impact of negative factors on the population and workers in Russia, the best available technologies (BAT) are applied. They include development and implementation of a noise management and control plan as a part of an environmental management system, proper location of noisy equipment, usage of low noisy equipment and noise reduction at its exploitation, use of measures to prevent the distribution of noise. The acoustical efficiency of the BATs for metallurgical production is estimated as 3-25 dB(A).

One of the protection measures used in Russia is installation of sanitary protective zones, i.e. areas ensuring the reduction of noise exposure to values established by hygiene standards, where placement of residential buildings is strictly prohibited. Developments of sanitary protective zones are usually carried out using noise maps. The usage of noise protection measures can significantly reduce a size of sanitary protective zone.

To reduce noise of flame furnaces it is proposed to switch to oxygen combustion technology, when the noise levels will decrease by 5-6 dB(A). Another way to reduce noise is to choose flameless and silent burners; noise reduction is estimated as 10-14 dB(A). Modern sound absorbing lining helps to reduce noise by 2 dB(A). In addition, usage of noise protection chamber reduces furnace noise by 15-20 dB(A).

Noise of rolling production can be reduced by 8 dB(A) with vibration-damping lining of guides at pipe rolling facility. Noise of loading and unloading operations of pipes can be reduced with silencer-plugs by 3 dB(A).

The total noise levels of the metallurgical plant on the way of its propagation can be reduced by 20 dB(A) using acoustic barriers. Usage of the complex noise-reduction measures insures provision of limit noise values at the workplaces and in residential building.

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